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Wireless Sensor Network and Precision Agriculture: A Survey

#1Pritesh A. Patil , #2Dr. R. S. Deshpande

1p.patil.k@gmail.com
2raj.deshpande@yahoo.co.in

#1Dept of Information Technology, AISSMS IOIT, PUNE, India
#2Dept. of Electronics and Telecommunication, SCSMCOE, Nepti, A'nagar, India

ABSTRACT

Technology encroachment with effective solutions such as less cost, reduced size devices, less complexity, adaptability etc. lead Wireless Sensor Network(WSN) to be most widely used in numerous domains of real life. WSN usage in agriculture domain is it's one such application. The guidance from the agriculture specialist from crop management aspects sometimes does not reach to the farmers in time, due to which they are unable to get estimated yield and profit and burdened with huge debt. WSN's application in this domain has made the farmer community realize its huge benefit. This state-of-the art technology can enable the agriculture domain related activities with ease and accuracy. The sensors may be placed on the field to acquire real time environmental parameters, soil's characteristics and pest detection and control. For this purpose WSN needs to frequently gather this information, but the sensor nodes poses limited resources. So it is necessary to optimize this frequency to effectively utilize the available resources. In this paper we have presented the review of the applications of WSN developed for agriculture domain and the challenges.

***Keywords*: Wireless sensor network, irrigation, Decision support system, pest control, fertilization.**

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I. INTRODUCTION

Agriculture has engaged in recreation and the development of the nation. Nations are applying additional efforts and special techniques to increase the food production, due to the increased demand of food. Alongside the need of cotton is also increasing with the rapid pace, as it became one of the most important needs of daily life. So increasing the production rate and quality of cotton should be given the same priority. Use of state-of the-art technologies towards agriculture is one such effort. Besides the scientific approach in agriculture, the information technology is being most widely realized in this area. Technologies like satellite navigation, sensor network, grid computing, ubiquitous computing and the context-aware computing are supporting the said domain for improved monitoring and decision making capabilities. The present condition of farmers in India is worth paying attention as the environmental factors are affecting the production and quality of crops. Due to which they are unable to get estimated yield and profit and burdened with huge debts, leading to create insecurity among them. Soil's natural factors can be analyzed as the type of farmland surface and network information. Centre of attention of agriculture environment information technology is to develop methods to congregate process, amalgamate and relate environmental information. Obtaining the crop growth, environmental parameter and variable information correctly and quickly is the primary challenge as farm region are not uniform and the significant variation in environmental conditions. Wireless sensor network (WSN) technology has been realized as the key technical means to handle and solve the above problems. WSN to strengthen agriculture consists of integrated sensor nodes positioned in the targeted region of farmland. These sensor nodes assist each other, recognize and monitor real-time soil and weather related parameters. The collected data is forwarded to the decision making system, which remotely monitors and provides proper management of agriculture process. Organization of paper is been done in six sections. Section I deals with the introduction and significance of WSN in agriculture domain. Section II describes the role and importance of sensors in agriculture. Section III briefly defining the tasks that WSN needs to carry out in general. Section IV gives the overview of the different application designed, deployed and implemented for agriculture. In section V challenges and directions are highlighted followed by references.

Significance of sensors in agriculture

For collecting physical and environmental attributes, sensors are most widely used in agriculture scenario. The sensed information by sensor that characterizes objects and environment are used to identify pastures, locations, objects and their state known as context. Obtaining these context information are useful in modelling agriculture like domains.

Following are the needs possessed by the agriculture domain:

a) Collection of atmospheric information.
b) Pesticides requirement against the attack of different characterized pests.
c) Gathering crop growth and soil information.
d) Monitoring of distributed land
e) Multiple crops on single piece of land
f) Nitrogen, Phosphate and Potassium % requirement for the fertility of soil.
g) Water requirement to different pieces of uneven land
h) Varied requirements of crops for different weather and soil conditions
i) Proactive solutions rather than reactive solutions.

Above listed requirements highly demand parallel and distributed application and processing. Application specific characteristic of WSN lead us to consider it as the highly prioritized means to collect essential information and respond to various situations. Alongside to have processed information out of raw sensor data a decision support system entails its importance. There are one to one relations between the time stamps and sensing of target for a sensor node, means a sensor node can sense exactly one target at each time instance. The active sensors with the associated program are able to sense the specific targets within its sensing region. For example, a sensor node can conduct wetness measure and pest detection etc. This data will be kept and utilized for future analysis and predictions.

Wireless Sensor Network

Technology advancement and small size of sensor attracts the manufacturers and users of automation tools in real life. Sensors can convert the observed physical attributes to signals. Bio-sensors are the examples showing that sensors are there in living objects such as human, plants, animals etc. WSN consists of various elements known as nodes. These nodes are deployed to collect application specific information. The network perform following three functions:

a. Sensing: to collect the required data.
b. Communication: Nodes communicate with base station and base station with controller.
c. Computation: This is done using microcontroller, hardware and programs.

The nodes which are dispersed over the field and instructed to collect the information are known as the source nodes. Sink nodes are those nodes which gather information from source node for further processing. Whenever there is a need to communicate with external network these sink nodes act as gateway node shown in Figure 1.

Communication Technology

Now a day, numerous wireless communication technologies are available such as WiFi, Bluetooth, Zigbee and Wibree etc. with different characteristics. Higher range of communication, low cost and low energy consumption of Zigbee has made it preferred over other technologies for design of WSN. There are 16, 5MHz channel operates on free and unlicensed frequency band i.e. 2.4 GHz [21].

Sensor Node Architecture

Sensor nodes are the backbone of WSN. It consists of four basic modules:

a. Programmable sensor module,
b. Radio module
c. Processor module and
d. Battery module.

The optional module i.e. memory module is needed whenever data storage is required for decision making shown in figure 2. Making of sensor nodes should be carried out under considerations viz. energy efficiency, scalability, robustness, adaptability or peer compatibility, size etc. As per the requirement of application domain such as agriculture, problem and distribution pattern, the sensor nodes need to be selected. The processor specification, memory, frequency band, available sensors, transmission range and size are the major useful characteristics of sensor node that make it preferable over others. There is a requirement of computation for the tasks in agriculture field like local decision making, in-net processing, and energy management using sleep and awake modes etc. in sensor network. To fulfil this requirement processor module is embedded with microcontroller (Figure 2) which plays a crucial role in terms of providing computation power in the network.

II. APPLICATIONS OF WSN IN AGRICULTURE

Wireless Sensor Network is one the state-of-the-art wireless communication technologies, which has secured unbeaten position in terms of its utilization in agriculture domain. The most important services under agriculture process such as irrigation, pest control, object detection and fertilization are surveyed in this part.

A. Irrigation

Irrigation if the non-natural provisioning of water in the farm land, which has become one of the major essential requirements of agriculture process. Water deficient areas require to optimize the use of water in such a fashion that provisioning of water only in those parts of the area which need it in required amount. Several mechanisms like drip section irrigation, sprinkler irrigation etc. are deployed to avoid the wasteful use of water over the traditional methods such as flood irrigation, channel irrigation. Following are the designs and developments enriched with the efficient use of WSN in agriculture domain for irrigation:

Aqeel et al. [1] presented extensive survey on WSN usage in agricultural for irrigation of piece of farm land, several systems and techniques have been designed.

Perez et al.[2] described the terms for the development of various applications for agriculture field using WSN. In this work application is divided into parts and based on input and output values specific action that need to be taken is been informed to the farmers. For this purpose decision support system which works based on the sensed information values by sensor node that lead to the requirement of irrigation of farmland.

R. Evans et al.[3] used Bluetooth as communication medium for the integration of on-field deployed WSN to implement range specific sprinkler control and developed decision support software. The main components of this system are machine convertor, localization and mission planning. First task is to convert self-moving irrigation machine from conventional system into electronically controllable system. Then self-positioning system monitors the geographic position of irrigation machine. If it is observed that the machine is controllable and accessible then time for irrigation is been decided by mission planning.
A. Babu et al. [4] developed and irrigation system in which environmental factors such as soil moisture, temperature and light intensity are measured using TDMA-based MAC protocol. Initially the sensors are in idle mode and change its state to active mode to measure the temperature and soil moisture. Local base station node instructs the sensor nodes to collect these environmental parameters. The nodes will update the sink node with the current value of temperature and moisture. The instructed nodes are only taking part in

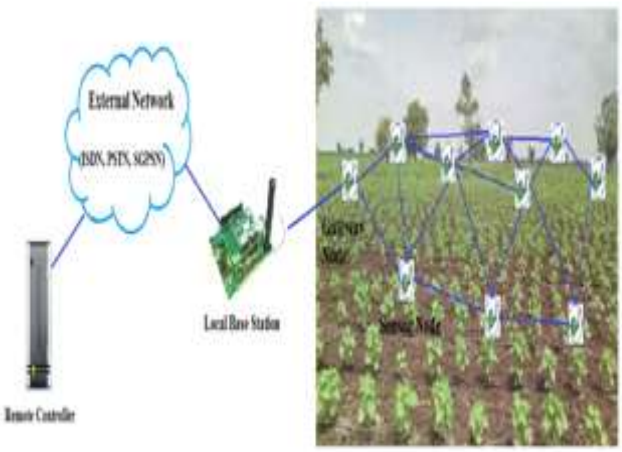


Figure 1. Wireless Sensor Network in Agriculture

W Iversen et al. [5] proposed a remotely sensed and controlled irrigation system using distributed WSN. The sensor nodes dispersed across the field to observe the soil condition. This data is collected after a fixed time interval and handed over to the base station for its further processing and necessary action.

M Zhi et al. [6] presented fuzzy based water-saving irrigation system. The sensor node measure the moisture error of soil and its change rate to obtain the amount of water required by crop for certain moisture level.

Dubey et al. [7] proposed a DTMF based remote irrigation control system using WSN. The system works on the basic principles of signals and systems to control the water flow in sprinkler or drip irrigation on partitioned farm land.

J. Guo et al. [8] developed a standard method in irrigation system for identifying soil wetness using information sharing. The system is efficient to identify the balance between the soil sensor performance and agriculture production.

Prados et al. [9] designed the irrigation system for the agriculture region in Spain, which was having remote control feature. The testing of the system gave them positive results in terms of water conservation up to 30-60%. In this work the farming region was divided into seven sub-parts. Each sub-part was monitored by control sector. All seven control sectors were connected through WiFi network.

C. Serodio et al. [10] proposed WDAN (Wireless Data Acquisition Network) to gather environmental related data along with soil moisture for smart irrigation in Portugal. For increasing the efficiency of irrigation system many SQWAS (Solar Powered Wireless Data-Acquisition Station) have been designed and placed for the measured of above mentioned factors.

Thool et al. [11] implemented a remote data acquiring, computer based drip irrigation system. This work also emphasized on the importance of data aggregation for further statistical analysis to predict the need of irrigation by various
crops.

Stefanos et al. [23] proposed ECHERP energy efficient WSN routing protocol for automated irregation system with effect for the field having same characteristics on demand of water.

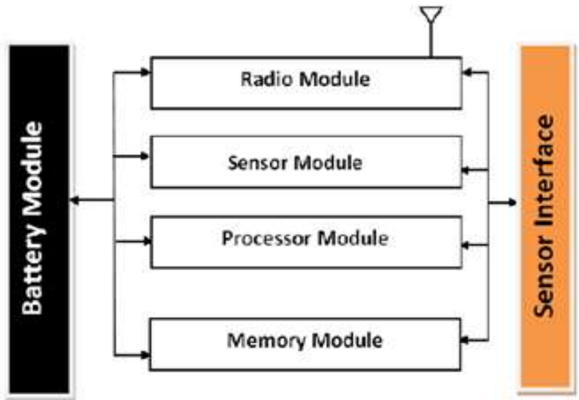


Figure 2. Sensor Node Architecture

B. **Fertilization**

To maintain and increase the fertility of soil so that plant growth will be as per the expected norms and the quality of flowering and fruiting to be appropriate, fertilizers are required, as the fertility of soil degrades due to multiple yields taken from the same piece of farm land. Identifying the location of part of the farm land which require optimum amount of fertilization is a tedious task and require to incorporate wireless sensor network.

U Voelker et al. [12] developed and tested moving head sensor mechanism for site specific fertilization. This mechanism was placed at the front of the vehicle used to measure the density of crop. Fertilizer spreader, a modified CAN-bus onboard computer and task calculator were used together, to calculate the necessity of nitrogen in the farm land.

Miller et al. [13] used GPS, real-time sensors and Bluetooth technology in design of automated fertilizer spreader which consists of input, decision support and output modules. The data values obtained by GPS and sensors are provided to decision support system (DSS) through input module. This DSS estimates the optimum quantity and spread patterns of fertilizer depending upon the real-time sensed data using Bluetooth technology. Rate of applying fertilizer ere controlled by the output of DSS.

Wang et al. [14] designed and implemented optimal fertilization DSS using WiFi of wireless sensor nodes and GPS analysis server. Field and surrounding real time data such as soil moisture, conductivity, temperature, humidity, CO_2 concentration etc. were acquired by sensors. User interactive GUIs were developed in their work. Energy efficiency was realized as GIS analysis servers were used to interpolate the data from small experiment plots to longer plots for exploiting data reduction. 3 factors (Nitrogen, Phosphorous and Potassium) i.e. NPK, 4 levels and 14 treatments test[15] of fertilizer was utilized by decision making system in[14].

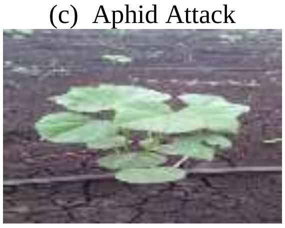
C. Pest Control

Pest management and control strategies in agriculture domain are one the key concerns to realize high yield. Pests may start attacking the crop right from the seedling stage to flowering and fruiting stage with straight affect on the growth of plant and the outcome from the farm land.In case of the cotton crop, the attack at seedling stage is done by fungi, due to imbalance of moisture below the ground which resist the conversion of seeds into plants. When the plants are 45-50 days old from that stage, the leaves and flowers of cotton plants are majorly attacked by thrips and aphids mostly comes in very large quantity.

(a) Thips attack

(b) Fruit Borer

(c) Aphid Attack



(d) Leaf roller

Figure 3. Infected leaves and boll by pests.
[a,b,c Courtesy: www.agritech.tnau.ac.in]

Thrips causes shrivelling of leaves due to scrapping of epidermis and desapping, also silvery shine on the under surface of leaves. Aphid infesting tender shoots and under surface of the leaves and cause curling and wrinkling of leaves. There are many other types of pests such as Fruit borer, leaf roller, whitefly etc. each pest's characteristics and time of attack is different as shown below. So early detection, management and control of these pests is highly essential to get the estimated yield. Following are the schemes presented for pest control in agriculture domain using wireless sensor network. Apart from irrigation and fertilization, sensors are also used to monitor and control fungus and pest problems. System to control phytoptora infection in potatoes was proposed in[16]. In this system sensors were placed on field to obtain humidity and environmental temperature, using this infection was reduced upto a great extent.

Specified slots of crop are infected by fungus which requires non-uniform spray of fungicides rather than uniform for the whole field. Non-uniform field sprayer controlled by CROP-meter was designed in[17]. Real time sensors were used to obtain biomass density of plant in CROP-meter. This captured information was utilized by the algorithm to control the composition of fungicides to be sprayed by field sprayer.

A. Sahua et al[18] developed COMMON-sense WSN for observing various environmental factors and installed in partially dry region of India.

CDAC Hyderabad designed U-Agri, which was claimed to be as low-cost WSN with decision support system by considering micro and macro environmental information of peanut crop and pests such as leaf roller and leaf spot[19].

Vaccari et al.[20] implemented WSN which remotely monitors and gather real-time data of micro-barometrical parameters in a vineyard farmland.

Abel et al. [22] formed wireless sensor network by incorporating internal and exterior cameras mounted in sensor nodes, installed in a vineyard in Italy, which remotely monitors the farmland. This implementation was with limitations on sensor node and fixed area and needs implementation on large scale.

D. Sustainable Agriculture

Wang et al. [26] developed a cluster model based on correlation of data generated by sensors for smart high-tunnel greenhouse. The model is designed by dual-model system where both sensor node and base station involved in modelling process.

Lihua et al.[27] implemented a system to evaluate the corn leaf water content based on the electrical properties of it. They conducted tests for three cases, 1) dry base water contents 2) wet base water contents and 3) relative water contents.

Ivanov et al [28] presented the analytics in the precision agriculture which includes monitoring, automation, data fusion, edge mining, and location and user awareness.

However nodes of WSN are themselves capable to execute some of the data analytics' functionality.

III. CHALLENGES AND DIRECTIONS

Self organization and flexibility feature of wireless sensor network have made it highly application specific. Due to this nature of WSN it is used for wide variety of areas such as forests, military services, under water monitoring, weather forecasting, agriculture etc.Inspite of this huge scope, WSN incurs several issues and requirement that need to be addressed for sustainability of the deployed system for long duration. The operations performed by the nodes of wireless sensor network are monotonous in nature as a result this will give rise to the mostly experienced issue of energy inefficiency. Proactive design requirements of the network include issues in designing communication protocols and deployment issues such as node and sensor placement. Agriculture domain is one of the areas which have not been given much emphasis in India in terms of using WSN to realize precision farming. Our work is focused towards the issues of WSN in agriculture domain.There may be different characteristics of farm land, resources and environmental factors. Sensor placement in open and harsh environment pose various design and deployment issues. These issues are listed below:

A. Energy Constraints

The task assigned to sensor node in the network is to identify the event, processing and transmission of data. In multi-hop network the sensor nodes are burdened with additional task of routing the packets. The above mentioned tasks are energy consuming. Sensor nodes are made-up with a restricted and predetermined A3 lithium battery power on which the liveliness of node greatly depends. To increase the battery life appropriate energy mechanisms in hardware and software can be used. Instead of these batteries solar cell battery which is very expensive solution but using renewable energy source to recharge the battery can be used. Because of the proactive approach of configuration of sensor network in agriculture, sensor nodes can get power by replaced batteries as node’s location is predefined.

B. In-Net Processing

At the time of sensing and measuring data, processing and transmission energy is depleted. An efficient data aggregation and optimized frequency rate of observation is required to be programmed so that along with the necessary data is collected, energy is also saved. On the other hand large amount of battery power is speedily drained due to frequent data collection. In case of agriculture domain the sensing rate can be adjusted as per the environmental condition, type of crop and resources. In this domain the sensing rate for data collection not usually high.For realizing less no of transmission to save energy, local storage can be considered at node level and intelligent transmission of data i.e. aggregated values or only changed ones. Implementation of sleep/awake mode can strengthen the network performance by saving energy as the node can awake in case of transmission only. For ensuring the reliability of the communication link the nodes should be kept closer to each other. However terrain features in agriculture land may act as obstacle to this reliable multi-hop communication.

C. Fault Tolerance

In agriculture field the node kept in open and harsh environment are inevitable to physical damage, obstruction and hindrance. In terms of maintaining reliability, failure of one node should not affect the entire network. Redundancy of sensor network reorganization and overlapped sensing regions are some of the techniques to increase fault tolerance or reliability of the network.

D. Sensor size and Capping

The sensor node should be small in size so that it can be suitable for deployment. To avoid the effect of temperature, rain and other environmental factors and the activities which can cause harm to material of the nodes by maltreatment by human or animals, they must be kept in defensive capping.

E. Sensor node position

Fixing the position of sensor nodes is many of the times the addressable important issue in the design of wireless sensor network in agriculture like domain. Sensor placement and design as per the need of application plays a very important role in reliability and monotony.

To measure the instructed parameters without disturbance accurately, the sensors must be placed on the such locations so that entire expected area is covered i.e. placement of light sensors on some height so as to avoid the shades caused by plant and achieve accurate values of light intensity. Unlike light sensors, the soil wetness sensor must be placed as close as possible to the farm land surface to accurately measure the wetness level so that necessary irrigation can be done if wetness falls below the threshold. Also solid fixation to nodes is required as strong wind, rain water may cause change in the position of nodes.

IV. CONCLUSION

In this paper we have reviewed and surveyed the applications of WSNs to Precision Agriculture. From this study, it is been concluded that, the existing applications developed and implemented for agriculture process are not easy to operate, manage, control and monitor the agriculture related parameters like soil and leaf wetness, fertility of soil, and pest management and control. It is also been witnessed here that there is a need of generalized solutions for different services and problems. Most of the work done hitherto in this field is focusing either on data acquisition/ processing or network related issues. There is potential need to develop a robust, energy efficient and cost effective solution, so that every farmer can leverage the state-of-the-art technology associated with WSN and precision agriculture.

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